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Puget Sound Intertidal Habitat Inventory 1996: Vegetation and Shoreline Characteristics Classification Methods

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EXECUTIVE SUMMARY

Puget Sound's intertidal areas provide habitat for species of commercial, recreational, biotic, and aesthetic value. Habitat is a critical ecosystem component -- it provides living space for permanent and transitory species, and supports primary production, food webs, and other ecosystem functions. Accurate information on the quality and quantity of intertidal habitats is important to monitoring and sustaining the health of Puget Sound.

This paper summarizes methods used to survey intertidal habitat in the Puget Sound by the Nearshore Habitat Program. The program is in the Washington State Department of Natural Resources' Aquatic Resources Division, and part of an ongoing project to monitor the Puget Sound nearshore environment through the Puget Sound Ambient Monitoring Program (PSAMP).

During the summer of 1996 and 1997, approximately 230 miles of shoreline were surveyed in Skagit County from the northern Skagit County border southward to the north fork of the Skagit River, and northern Whidbey Island in Island County. Paper and digital versions of inventory data and documentation are available through the Nearshore Habitat Program. The data sets are intended for use in general resource management and land use planning.

The inventory describes two components of intertidal habitat: vegetation types and shoreline characteristics.

Vegetation Types
Eight nearshore vegetation types were classified using multispectral imagery: eelgrass, brown algae,

kelp, green algae, mixed algae, salt marsh, spit and berm vegetation, and red algae. The vegetation types encompass most common macroscopic vegetation found along Puget Sound's shorelines. They were selected based on aquatic resource management priorities and multispectral detection considerations.

Vegetation types were derived from multispectral imagery using ground data to guide the classification. Aerial imagery was collected during July when tides were below Mean Lower Low Water in most of the study area and at sun angles which minimized sun glint. A CASI (Compact Airborne Spectrographic Imager) sensor collected 11 bands of reflectance data, ranging from 470 nanometers (nm) to 876 nm, at a resolution of approximately 13 feet (4 meters). Color infrared photography was collected simultaneously at 1:11,000 scale. The imagery was rectified using Global Positioning System (GPS) data collected in-flight, and control gained from Washington State Department of Natural Resources' digital orthophotographs. Most areas were mapped to within 40 feet (12 meters) relative to the control points.

Ground data were collected throughout the study area between June and September. The location of sites with greater than 25% vegetation cover were recorded using differentially corrected Global Positioning System (DGPS) data or aerial photograph annotation. Sites were assigned to one of eight vegetation classes, according to the type that comprised 75% or more of the vegetated cover. Sites were then divided into groups and used: (1) to guide classification of multispectral CASI imagery, or (2) to assess the accuracy of the classified image. Overall classification accuracy was 86.4%. The classified raster CASI data were then translated into a vector coverage and generalized.

Shoreline Characteristics
Physical attributes in intertidal areas were characterized according to *A Marine and Estuarine Habitat Classification System for Washington State* (Dethier, 1990). This system builds on the National Wetland Inventory system (Cowardin *et al*., 1979), with modifications relevant to marine and estuarine communities. The following classification levels were delineated: System, Subsystem, Substrate, Energy, and Water Regime.

Intertidal shoreline classification was completed using ground data and field annotation of photos in conjunction with photo-interpretation of color infrared aerial photographs ranging between 1:11,000 and 1:12,000 scale. The minimum mapping unit was approximately 0.2 hectares (0.5 acres). Final delineations were completed on 1:12,000 scale DNR orthophoto maps using a Zoom Transfer Scope and then digitized.

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INTRODUCTION *(to Table of Contents)*

Nearshore habitats have significant biological, ecological and economic value. They are important sites for human activities, including commerce, navigation, aquaculture, and recreation. They are also one of the most productive areas in the marine ecosystem. Most marine vegetation and animals depend on nearshore habitats for at least a portion of their life cycle. Human activities have severely impacted nearshore areas, especially in population centers in Puget Sound (Bortleson, 1980; Thom and Hallum, 1991; Bailey *et al*, 1998). In recognition of the critical role of nearshore habitats and the magnitude of losses that have occurred, minimization of nearshore habitat loss has been identified as the most important management action to protect ecosystem health in Puget Sound and Georgia Basin (British Columbia/Washington Marine Science Panel, 1994).

The objective of the Nearshore Habitat Program (NHP) is to inventory and monitor the health of intertidal and shallow subtidal habitats in Puget Sound. The Nearshore Habitat Program maps the distribution and abundance of nearshore habitats, and monitors change over time in response to human and natural factors. Results are used to support a range of management and research activities, including aquatic land use planning, resource protection, habitat-related studies, and trend analysis

The Nearshore Habitat Program is in the Aquatic Resource Division of the Washington State Department of Natural Resources (DNR). DNR is responsible for managing more than two million acres of state-owned aquatic lands. The Nearshore Habitat Program is a component of a multi-agency research effort organized under the Puget Sound Ambient Monitoring Program (PSAMP). PSAMP was established in 1988 through the Puget Sound Water Quality Management Plan to conduct long-term comprehensive monitoring of the Puget Sound environment and its resources. Monitoring is carried out by the Washington State Departments of Natural Resources, Fish and Wildlife, Health, and Ecology, and the US Fish and Wildlife Service

PSAMP defines nearshore habitats to include unvegetated and vegetated habitats in intertidal, shallow subtidal, and supratidal areas (Monitoring Management Committee, 1988). The geographic extent of the Puget Sound planning area is defined to include the Hood Canal, the southern, central and northern Puget Sound and Whidbey sub-basins, the San Juan Archipelago and the southern Strait of Georgia (Puget Sound Water Quality Authority, 1986). The PSAMP study area extends west to Cape Flattery at the edge of the Strait of Juan de Fuca and north to the international border between the US and Canada

In order to characterize habitat throughout the large study area with limited resources, the NHP assesses habitat at multiple scales of resolution. At the state-wide scale, over thousands of marine shoreline miles, the NHP inventories physical characteristics and biota using the ShoreZone Mapping System. The system provides a broad-brush characterization of habitat abundance and distribution by summarizing biophysical shoreline features for segments of shoreline on a digital GIS line coverage. In priority areas, which span hundreds of miles, the NHP produces medium-resolution polygon-based inventory data describing intertidal vegetation and physical characteristics. At reference sites, areas significantly less than 1 mile in size, high resolution data collection methods are used to census shoreline characteristics and biota

This document describes medium-resolution methods used to inventory intertidal vegetation and shoreline characteristics in Skagit County and northern Whidbey Island in 1996. The 1996 Intertidal Habitat Inventory study area included approximately 230 miles of shoreline along the mainland from the northern Skagit County border in the Strait of Georgia to the north fork of the Skagit River, and the northern part of Whidbey Island in Island County (Figure 1).

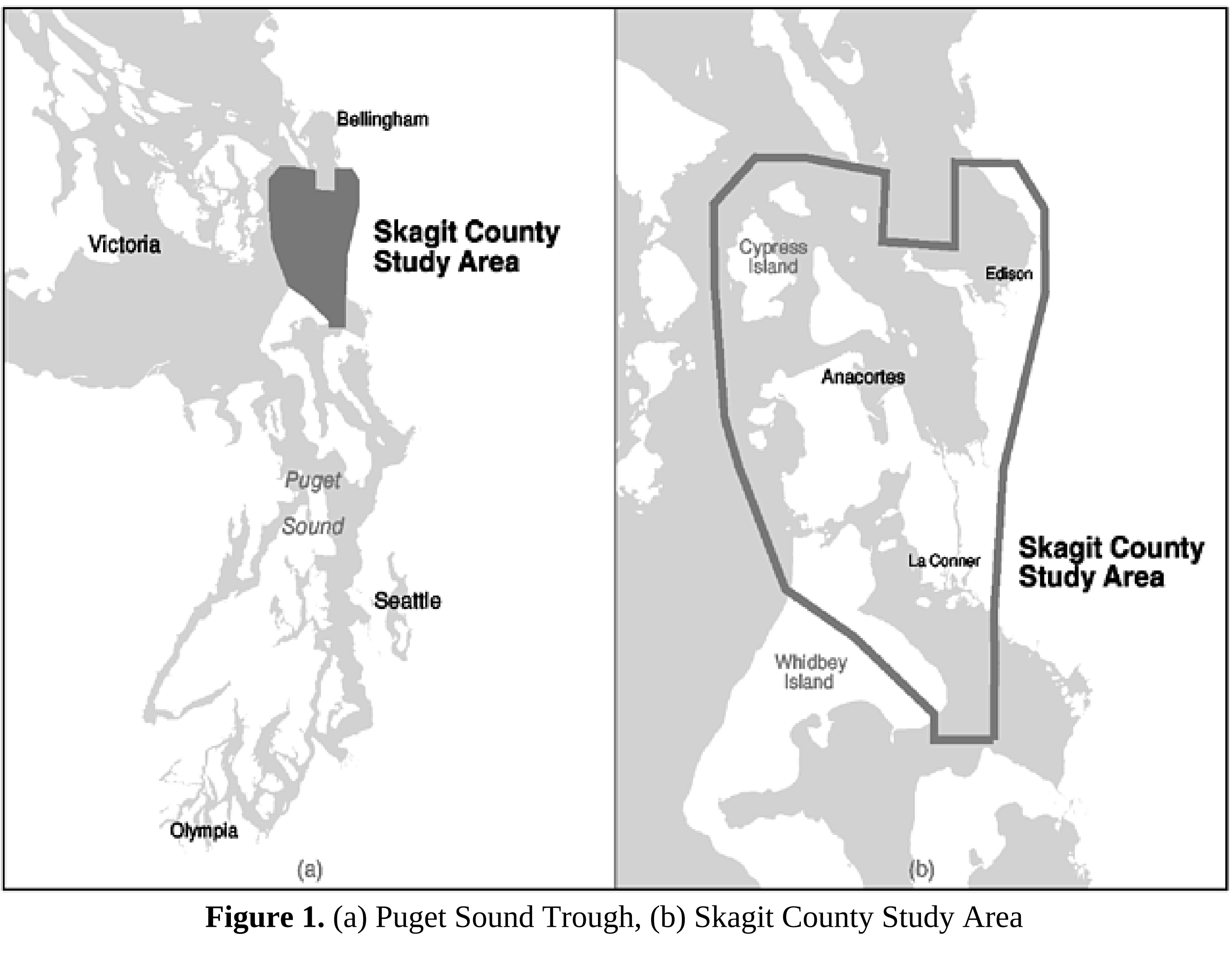


Figure 1. (a) Puget Sound Trough, (b) Skagit County Study Area

The area was selected as a priority for medium resolution inventory because of the diverse habitat conditions and current management issues relating to conservation, restoration, and development. The region supports a range of intertidal habitat types, including rocky and mixed coarse sediment beaches with relatively high wave energy, as well as sheltered sand and mud flats. The Puget Sound Environmental Atlas (Puget Sound Water Quality Authority, 1992) documented habitat use in the area by resident and nonresident populations such as forage fish, red rock and Dungeness crab, salmonids, groundfish, intertidal and subtidal shellfish, seabirds, and a variety of marine mammals. There is a wide range of land uses along the shoreline, including the urbanized waterfront of Anacortes, industrial sites, low and medium density residential housing, aquaculture, recreational areas, diked agricultural areas in the Skagit flats, and relatively undeveloped areas such as the DNR Cypress Island Natural Resource Conservation Area and the Padilla Bay National Estuarine Research Reserve.

VEGETATION INVENTORY *(to Table of Contents)*

Vegetation Types

Eight nearshore vegetation types were classified using multispectral imagery. The vegetation types encompass most common macroscopic vegetation found along Puget Sound's shorelines. They were selected based on aquatic resource management priorities and multispectral detection considerations. Descriptions follow algal taxonomy found in Scagel *et al.* (1989):

- Brown Algae - Algae belonging to the taxonomic group Division Phaeophyta. Some common representatives in Puget Sound include rockweed (*Fucus spp.*) and *Sargassum muticum*.

- Kelp - Large brown algae belonging to the taxonomic group Order Laminariales. Some common representatives in Puget Sound include floating kelp (*Nereocystis luetkeana*) and understory kelp (*Laminaria spp.*). Because of its recognized ecological function and management importance, kelp is distinguished from other brown algae when it makes up greater than 75% of the vegetated cover.

- Eelgrass - The vascular plants *Zostera marina, Zostera japonica, Phyllospadix spp. and Ruppia maritima*. Eelgrass beds (*Z. marina*) are recognized as critical habitat in the life cycles of many fishes, invertebrates and birds.

- Green Algae - Algae belonging to the taxonomic group Division Chlorophyta. A common representative in Puget Sound region is sea lettuce (*Ulva spp.*).

- Red Algae - Algae belonging to the taxonomic group Division Rhodophyta. A common representative in Puget Sound region is nori (*Porphyra spp.*). Areas dominated by red algae and large enough to map at this resolution rarely occur in the summer in the intertidal zone of Puget Sound.

- Mixed Algae - Areas in which red, green, or brown algae coexist, but no single type occupies more than 75% of the vegetated cover.
- Salt Marsh - Salt-tolerant, emergent wetland plants such as pickleweed (*Salicornia virginica*), saltgrass (*Distichlis spicata*), and sedge (*Carex lyngbyei*). Freshwater marsh areas were not included in the inventory.
- Spit and Berm Communities - Areas dominantly covered with plants such as dune grass (*Leymus mollis*), gumweed (*Grindelia integrifolia*), and yarrow (*Achillea millefolium*), which generally occur above the highest tides, but still receive salt influence. The substrate is usually sand or gravel, and drift logs commonly accumulate.

The list of vegetation types to be classified was influenced largely by spectral discrimination considerations (Aitken *et al.*, February 1995); yet, management priorities led to the selection of some vegetation classes despite discrimination difficulties. For example, the spectral signature for mixed algae varies with species composition, yet the mixed category was required in order to identify the presence of vegetation of varying composition.

Kelp and other brown algae have similar dominant pigments and often a similar spectral signature. However, the inventory needed to differentiate kelp because of its recognized ecological function (e.g., Foster & Shiel, 1985; Dayton, 1985; Duggins, 1988; Wheeler, 1990) and management considerations (e.g., Washington Administrative Code (WAC) 220-110-250; WAC 365-190-080; DNR POL-0300).

Although both green algae and eelgrass contain chlorophyll *a* and *b* pigments and have a similar spectral profile, management considerations required that they be differentiated. Eelgrass beds have recognized ecological function (e.g., Phillips, 1984) and management considerations (e.g., WAC 220-110-250; WAC 365-190-080; DNR Policy 0300, 1991; Wyllie-Echeverria et al., 1994). Green algae can be an indicator of other processes such as eutrophication.

Salt marsh and spit or berm communities are often narrow and obscured by overhanging vegetation, making discrimination difficult using current methods. Despite spectral and spatial discrimination challenges, the salt marsh, and spit or berm categories were included due to the recognized functional importance of wetlands, and because habitats at the land-water interface tend to be impacted highly by development. Additionally, salt marshes have recognized ecological functions (e.g., Seliskar & Gallager, 1983) and management considerations (e.g., WAC 220-110-250; WAC 365-190-080; DNR POL-0300)

Vegetation Inventory Field Data Collection *(to Table of Contents)*

Field data were collected by Nearshore Habitat Program (NHP) scientists throughout the study area when tides were below +1.0 mean lower low water (MLLW), between June and September in 1996 and 1997. The minimum mapping unit (MMU) was approximately 13 feet (4 meters). Information on vegetated sites were located by either differentially corrected Global Position System, or annotated aerial photographs with transparent overlays. Additionally, 35 mm slides were taken of vegetation features at regular intervals along the shoreline and at all DGPS-located sites. Field data were collected by boat or on foot. Areas to be surveyed were identified in advance by apportioning the available field days over the study area as a whole, and considering access to the shoreline. During the field season, a tally of the number of sites for each vegetation class was maintained to ensure that field data representing each of the vegetation classes were collected throughout the study area.

Field sites that had a total vegetation cover greater than 25 percent were recorded as vegetated sites. Vegetation class assignments were based on the dominant vegetation category at a site, i.e., the vegetation class making up 75 percent or more of the vegetated area. A crucial factor in selecting field sites was to consider the appearance of vegetation patches from a planimetric perspective. Discussions between field, GIS, and remote sensing staff led to refining field data collection conventions, e.g., applying the minimum mapping unit to the horizontal expanse of the landscape (the sensor's vantage point), and recording percent cover of vegetation and cover class of vegetation as viewed from above. To ensure consistency, certain tasks, particularly, aerial photography annotation, were limited to select staff.

The data set for a field site consists of (1) 35 mm slides of each site and its surrounding features, (2) a form noting vegetation type, and, when possible, primary species composition and other physical parameters, and (3) annotated aerial photography that represent a feature as a polygon or line, or a GPS-located and delineated site (features were represented as point, line, or polygon depending on patch shape and location). After collection, GPS data were differentially corrected based on local base station data and converted to ARC/INFO coverages.

The majority of field sites were annotated on photography rather than located using DGPS. Photo annotation was a more rapid data collection method. Additionally, with the MMU at 13 feet and the positional accuracy of the multispectral imagery at +/- 40 feet, small DGPS-located sites could be difficult to precisely register to the image data due to positional differences between the two data sets. The annotated photography method provided critical visual clues for relating a field site to an image site. When positional discrepancy was in question with a DGPS-located site, we found that 35 mm slides taken of each site and its surrounding features were the best tools for determining site location within the imagery.

In the office, field data were assigned to one of two groups: (1) to guide the image classification process, or (2) to assess classification accuracy. Field sites were divided between the two groups so that data were distributed throughout the study area, and so that sites within each vegetation type were apportioned equally. When assigning sites, the staff confirmed that proximate field data did not contradict or overlap, and that the effects of spatial autocorrelation on the accuracy assessment methodology were kept to a minimum.

Imagery Acquisition *(to Table of Contents)*

The NHP contracted with Borstad Associates Ltd. in Sidney, British Columbia to collect, rectify, and mosaic imagery of nearshore areas in Skagit County and northern Whidbey Island. Digital multispectral imagery and simultaneously collected color infrared photography (at 1:11,000 scale) were acquired using a CASI (Compact Airborne Spectrographic Imager) sensor and a 12" focal length Zeiss mapping camera. Imagery was acquired at an approximately 169 square feet (16 square meters) spatial resolution on July 14, 15, and 30, 1996 during low tides.

The CASI is a passive, electro-optical imaging spectrometer. The 'push-broom' imager operates by looking down in a fixed direction, building a two-dimensional image as the aircraft moves forward. The instrument's spectral range is 400 nm to 1000 nm, and it has a 37.8 degree field of view. For the Skagit County project, the instrument was operating in spatial mode, programmed with a custom, 11-channel bandset as shown in Table 1 (Borstad, 1996).

Table 1. CASI Sensor Bandset for Skagit County Study Area (from Borstad, 1996).

Band No.	Wavelengths (nm)	Purpose
1	470-515	Chlorophyll *b* absorption at 480 nm Carotenoid reflectance peak at 500 nm Penetration of clear water
2	540-560	Green vegetation reflectance peak (eelgrass and green algae) Penetration of turbid water
3	575-590	Brown algae absorption well
4	600-615	First reflectance peak for brown algae
5	625-635	Well between reflectance peaks for brown algae
6	640-655	Second reflectance peak for brown algae, chlorophyll *b* absorption at 650 nm (eelgrass)
7	670-690	Absorption well for chlorophyll *a* (all vegetation)
8	704-714	Red rise, near infrared reflectance for shallow submerged and floating vegetation, but in avoiding 720 nm water vapor feature
9	743-755	Near infrared reflectance for submerged and floating vegetation, but in avoiding 762 nm water vapor feature

10	775-786	Near infrared reflectance for emerged and marsh vegetation, substrate delineation
11	854-876	Near infrared reflectance for emerged and marsh vegetation, substrate delineation

The CASI imagery collection system was composed of various components in addition to the sensor (Aitken *et al.*, June 1995). A low wattage 486 computer recorded roll and pitch from a two-axis gyroscope. The analog signal from the gyroscope was converted to digital form, and recorded on the computer's hard drive. Yaw was measured using a flux-gate compass. GPS recorded horizontal and vertical movement information (drift, ground speed, and altitude changes) of the aircraft. GPS base station data were used to differentially correct the aircraft's rover GPS data in post-processing. The raw image data were acquired with 12 bit precision and written in unsigned 16 bit format onto 8 mm tape.

The CASI system was mounted in a Cessna T210 aircraft. All flight lines were flown at a 10,800' altitude, from south to north, with 50% sidelap between adjacent flight lines. Flying in a consistent direction reduced radiometric discrepancies due to sun angle and sensor viewing angle. Target dates for image acquisition were selected based on maximum intertidal exposure (minus 1.0 foot mean lower low water or below), and times when sun angle would reduce sun-glint. Actual date, tidal levels, and time of day that each flight line was collected are listed in Table 2.

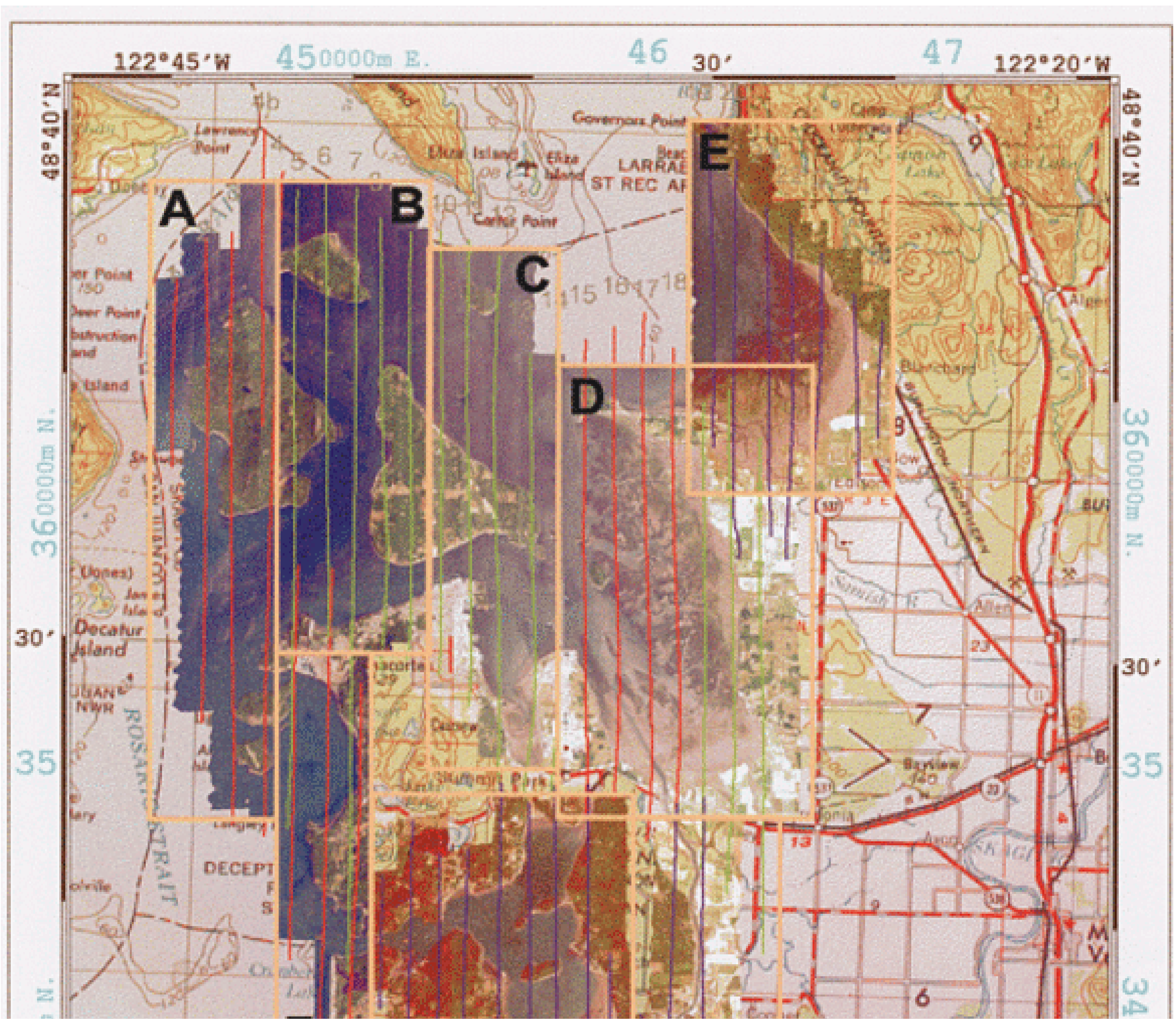
Table 2. Imagery Collection Date, Time and Tidal Elevation for Skagit County Study Area

Flight Line	Date	Start Time (PDT)	Tide (MLLW)	Flight Line	Date	Start Time (PDT)	Tide (MLLW)
1	July 14	11:45 AM	-0.6	13 South	July 30	11:05 AM	-1.9
2	July 14	11:30 AM	-0.8	14 North	July 15	11:59 AM	-0.8
3	July 14	11:13 AM	-0.9	14 South	July 30	11:17 AM	-2.3
4 North	July 14	11:55 AM	-0.4	15 North	July 14	12:11 PM	-0.6
4 South	July 14	10:55 AM	-0.6	15 South	July 30	11:30 AM	-2.3

5 North	July 15	09:54 AM	-0.3	16 North	July 14	12:26 PM	-0.1
5 South	July 14	10:42 AM	-0.8	16 South	July 30	11:43 AM	-2.4
6 North	July 15	10:09 AM	-0.3	17 North	July 14	12:41 PM	0.1
6 South	July 14	10:26 AM	-0.8	17 South	July 30	11:52 AM	-2.4
7 North	July 15	10:30 AM	-0.7	18 North	July 14	12:55 PM	0.5
7 South	July 14	10:11 AM	-0.9	18 South	July 30	12:05 PM	-2.4
8 North	July 15	10:44 AM	-1	19 North	July 30	01:06 PM	-0.9
8 South	July 30	10:18 AM	-1.1	19 Central	July 15	12:22 PM	-0.9
9 North	July 15	11:00 AM	-1	19 South	July 30	12:21 PM	-2.2
9 South	July 30	10:25 AM	-1.1	20 North	July 30	12:45 PM	-0.9
10 North	July 15	11:14 AM	-1	20 Central	July 15	12:37 PM	-0.9
10 South	July 30	10:35 AM	-1.1	20 South	July 30	12:38 PM	-1.6
11 North	July 15	11:27 AM	-1	21 North	July 30	01:16 PM	-0.5
11 South	July 30	10:43 AM	-1.1	21 South	July 15	12:53 PM	-0.7
12 North	July 15	11:42 AM	-0.9	22	July 30	01:26 PM	0

12 South	July 30	10:53 AM	-1.9	23	July 30	01:36 PM	0.5
13 North	July 15	11:56 AM	-0.8	24	July 30	01:44 PM	0.5

Imagery was adjusted to surface radiance by applying an atmosphere correction, corrected for roll, pitch and yaw and projected into geographic coordinates using DGPS data to yield 169 square feet (16 square meters) pixels (Borstad, 1997). The resulting imagery was warped to fit DNR's orthographic aerial photographs and coastline vectors in Washington State Plane, south zone, unit of measurement is feet, North American Datum of 1927 (NAD '27). The flight lines were rectified to within +/-3 pixels (approximately 40 feet) in most parts of the imagery. The rectified flight lines were mosaicked into eight, non-overlapping blocks, requiring 1174.1 MB of disk space. Figure 2 shows the CASI sensor flight lines and mosaic boundaries.



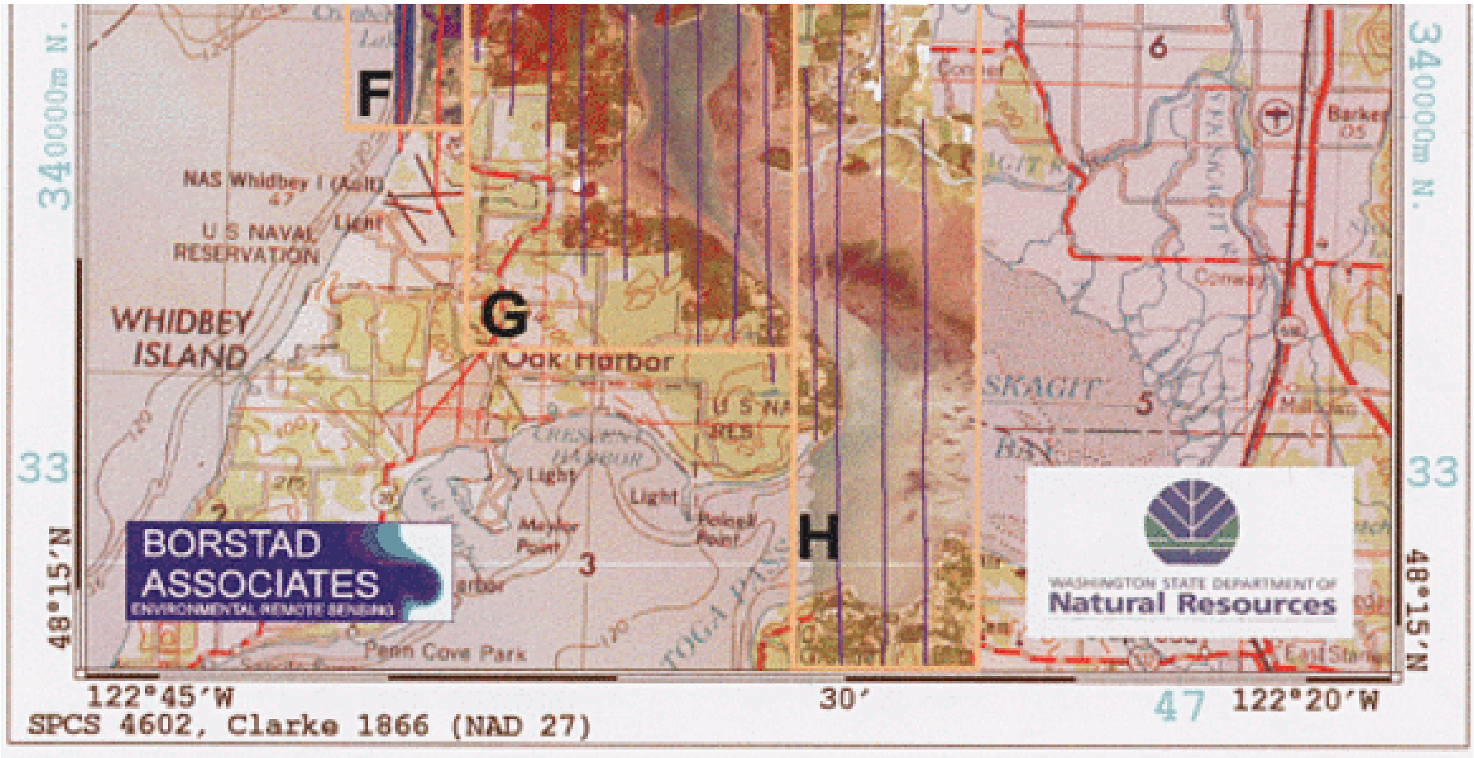


Figure 2. CASI Sensor Flight Lines and Mosaic Boundaries for Skagit County Study Area, red=July 14, green=July 15, blue=July 30 (from Borstad, 1997)

Image Processing and Analysis *(to Table of Contents)*

The NHP used Imagine 8.3 software (ERDAS, Inc., Atlanta, GA) running on a Sun workstation (Sun Microsystems, Inc., Mountain View, CA) to process the rectified, mosaicked, unsigned 16 bit image data. Classified files were produced using an iterative, hybrid approach to classification, combining unsupervised and supervised approaches. The unsupervised process used a minimum distance, iterative clustering algorithm that examined the raster image for statistically clustered radiance values. The supervised processing relied on the field data (e.g., DGPS-located sites and annotated photography) to develop training signature sets.

The nearshore vegetation layer was produced by running an iterative series of ERDAS Imagine routines that identify vegetated areas of interest, and eliminate areas of non-interest. The basic steps were:

(1) On-screen digitizing was used to create a polygon based file (.aoi) to eliminate areas of non-interest, e.g., uplands and open water.
(2) The .aoi file was used with the original multi-channel raster to produce the first masked multispectral raster.
(3) A maximum likelihood classifier with an unsupervised signature set was run on the masked multi-channel raster (from step 2) to produce the first classified file.
(4) Coarse editing on the first classified file was done to eliminate areas of non-interest, e.g., open water and substrate. Classes of non-interest were recoded to zero.
(5) Used pixel values assigned to nearshore vegetation types in the edited classified file (from step 4) to masked pixels in the original multi-channel raster, producing a second masked, multi-

channel raster.
(6) Developed a supervised signature set and an unsupervised signature set from the second masked multi-channel raster. Signatures from each set were evaluated, and in some cases modified or eliminated. The two signature sets were then combined into a single, `hybrid' signature set.
(7) A maximum likelihood classifier with the hybrid signature set was run on the masked multi-channel raster (from step 5) to produce the second classified file.
(8) Areas that accurately represented a nearshore vegetation class were interactively selected and recoded to the target class values for each land cover type.
(9) Again, produced a third masked, multi-channel raster by masking specific areas from the original multi-channel raster based on user selected digital values in the edited maximum likelihood classified file (from step 7).
(10) A maximum likelihood classifier with an unsupervised signature set was run on the masked multi-channel raster (from step 9) to produce a third classified file.
(11) Areas that accurately represented a nearshore vegetation classes were interactively selected and recoded to the target class values for each land cover type.
(12) Areas that continued to be a problem were sent through one more processing iteration. A maximum likelihood classifier with an unsupervised signature set was used for each iteration.
(13) Each time the classified file was reviewed, interactively edited, and recoded.
(14) A single composite classified files was created from the multiple classified files.

Classification of multispectral imagery depends on isolating a unique spectral signature for each category in the classification scheme. Vegetation has distinct reflectance characteristics in the visible and near infrared portions of the electromagnetic spectrum. When the pigmentation among the exposed vegetation types varies, e.g., green, red, and brown algae, the visible wavelengths (400 nm - 700 nm) provide good spectral discrimination (Swain and Davis, 1978). In the near infrared wavelengths (700 - 1300 nm), vegetative reflectance response is determined largely by intra-cellular structure and canopy structure (Swain and Davis, 1978). In cases where spectral discrimination was not sufficient to differentiate classes, alternative methods were used. Table 3 lists the areal extent for the eight vegetation types classified.

Table 3. Areal Extent of Nearshore Vegetation Types for Skagit County Study Area.

Vegetation Type	Acres
brown algae	68.68
green algae	1217.47
mixed algae	238.99
red algae	0.14

eelgrass	14416.43
kelp	199.68
salt marsh	946.87
spit or berm vegetation	1217.47

Kelp and other brown algae have similar dominant pigments and often a similar spectral signature. Contextual cues were used to separate kelp from other brown algae. In the case of *Fucus* spp., habitat context was used. While kelp is found mainly in the subtidal zone, *Fucus* is common to rocky beaches. The different viewing backgrounds of kelp and *Fucus* facilitate spectral discrimination. *Sargassum muticum* also forms canopies in the shallow subtidal. To differentiate *Sargassum muticum* from kelp we used pattern and context cues provided by the simultaneously acquired color infrared photography (CIR) photography.

Green algae and eelgrass both contain chlorophyll *a* and *b* pigments and have a similar spectral profile. At times, environmental context can be used to distinguish eelgrass and green algae. When green algae are on a tidal flat and eelgrass is located in the subtidal zone, the two can be identified by relying on the different spatial location and different substrate/water background cues. However, when these environmental cues are lacking, spectral separation is difficult. Green algae commonly grows intermixed with eelgrass, in these cases the areas were classified as eelgrass because eelgrass is the more persistent vegetation and is protected by regulation.

The spectral signature for mixed algae varies with species composition, and the layering of the different species. Mixed algae can be confused spectrally with any of the algal categories. However, the mixed algae category allows us to summarize species composition in a manner that keeps tractable the number of classification categories.

Salt marsh and spit and berm vegetation communities are separable from the macroalgae and eelgrass mainly because they contain emergent vegetation and the spectral signatures more closely resemble terrestrial vegetation (Aitken *et al.*, June 1995). Intertidal zonation is another important spatial cue, since these vegetation types occur in the upper intertidal and supratidal zones. To differentiate salt marsh and spit and berm communities from other terrestrial vegetation, the upland areas of non-interest were masked.

Detecting submerged vegetation was difficult. Spectral discrimination of submerged vegetation is influenced by a number of environmental conditions such as, water depth, surface roughness, water clarity and bottom type. Water attenuates the spectral response of submerged features. The longer wavelengths, e.g., near infrared, are absorbed in a few tenths of a meter of water (Lillesand and Kiefer, 1994). The water clarity and surface conditions of Puget Sound further hampers identification. Although the submerged feature is apparently vegetation, the vegetation type is not evident.

For vegetation, its type, vigor, density, moisture content, degree of exposure, and amount of coverage by epibenthos will all affect spectral response. In addition to the spectral characteristics of the features themselves, environmental factors influence the energy levels ultimately recorded by the sensor. Atmospheric particles also influence the signal recorded by the sensor by absorbing and scattering radiant energy. Vegetative response is affected also by the amount and type of its background, e.g., substrate or water. These variations have strong implications for image classification. Signature extension relies on applying the training data for a particular feature to all other sites in the imagery that represent that feature.

Classification Accuracy Assessment *(to Table of Contents)*

Understanding the accuracy and reliability of a data set is important to using it appropriately. This section summarizes classification accuracy assessment methods, findings, and implications. In order to be tractable, our accuracy assessment design balanced statistical validity with practical implementation issues.

Classification accuracy was assessed by comparing the classified image to a set of field sites (reference data) that had not been available to the image analysts during classification. Approximately one-third of all field sites were assigned as reference data for accuracy assessment. Reference data were chosen so they were a representative subset of all field sites, spread throughout the study area. The minimum number of field sites were reserved for accuracy assessment, so that the quality of the image classification was not compromised.

Classification accuracy was assessed by comparing the classified vegetation type to the field surveyed vegetation type and both class types being recorded. Plots of the classified data (at 1:12,000 scale) were used to evaluate the classification against reference data annotated on photography or maps. GPS-located field sites were overlaid onto the digital, composite classified file and evaluated on-screen. Because assessment sites included line and polygon features composed of multiple pixels, establishing 'correctness' was not always a 'all or none' decision. We assigned points as follows:

% of Feature Correctly Classified	Points Awarded
<33%	0
34 %- 66%	0.5
>66%	1

The points assigned during the classification accuracy assessment work for the Skagit County study area were compiled into an error matrix (Table 4). The number of assessment sites classified as a particular category is shown relative to the actual category as recorded in the field. In matrix form, commission and omission errors present in the classified data are identified readily.

Table 4. Nearshore Vegetation Classification Accuracy Assessment Results for the Skagit County Study Area.

Imagery Classified Data	Field/Reference Data								
	brown algae	green algae	kelp	mixed algae	eelgrass	salt marsh	spit/ berm	un-vegetated	total no. classified
brown algae	37.5	1	0	4.5	0	0	0	0	43
green algae	1	58	0	3	2	1	1.5	0	66.5
kelp	2.5	0	64	1	0	0	0	0	67.5
mixed algae	3.5	9.5	0	55.5	1.5	0	0	0	70
eelgrass	2	3	1	1	74.5	0	0.5	0	82
salt marsh	0	0	0	0.5	0	68	4	0	72.5
spit or berm	0	0	0	0	0	0.5	40	0	40.5
unvegetated	1.5	5.5	2	1.5	11	1.5	8	81	112
total reference sites	48	77	67	67	89	71	54	81	554

Two common descriptive techniques for analyzing an error matrix are producer's accuracy and user's accuracy (Congalton, 1991). Producer's accuracy is the probability of a reference site being correctly classified, i.e., a measure of omission error. It is the number of sites correctly classified as a land cover divided by the total number of reference sites for that land cover. User's accuracy indicates reliability, or the probability that a site classified on the image is really that land cover type on the ground. It is the number of sites correctly classified as a land cover divided by the total number of sites classified in that category. Table 5 shows Producer's and User's classification accuracy by land cover type.

Table 5. Producer's and User's Classification Accuracy Percentages by Land Cover Type for the Skagit County Study Area.

Classification Accuracy		
Land Cover	**Producer's %**	**User's %**
brown algae	78	87
green algae	75	87
kelp	96	95
mixed algae	83	79
eelgrass	84	91
salt marsh	96	94
spit or berm	74	99
unvegetated	100	72

Overall accuracy for the classified image was 86.4%. This result is approximately 10% higher than the previous classified image in the Whatcom County area (Berry and Ritter, 1997). Accuracy rates for individual vegetation types are encouraging with respect to prospective data set uses. Eelgrass, kelp and salt marsh vegetation, which are important to land-use related decision making, had generally high accuracy rates.

For most of the vegetation types, the User's Accuracy was higher than the Producer's Accuracy, pointing to a trend of omitting a vegetation feature from the classification (an omission error), rather than confusing it with something else (a commission error). For example, a person using the classification plot would be likely to a find a salt marsh site on the plot was indeed a salt marsh site on the ground, but may find salt marsh sites on the ground that were not classified on the plot (an omission error).

Multiple factors may have contributed to the pattern of higher omission error. The analyst's training signatures used by the statistically-based classifier to assign pixels to classes may not have represented the population. The percent cover threshold for a vegetated site (25 percent or greater) may have been too low at the lower limit for consistent detection. Temporal changes in vegetation could have occurred between the time at which the field data were collected and the time at which the multispectral imagery was collected, common short term changes include green algae blooms and changes in species composition.

Some accuracy rates reflect weaknesses in the methodology with respect to specific land cover types. Unvegetated areas had the highest Producer's Accuracy and the lowest User's Accuracy rates. We attributed the high Producer's Accuracy to the capability of the method to correctly identify the completely unvegetated field sites selected for evaluation. The low User's Accuracy rate results from the frequent classification of portions of vegetated field sites that are transitional or have low densities of vegetation as unvegetated.

Spit or berm vegetation had the highest User's Accuracy and the lowest Producer's Accuracy rates. This vegetation type was most often incorrectly classified as unvegetated, and also mis-classified as other various vegetation types. This result reflects the inherent weakness of current methods to detect spit or berm vegetation. Spit or berm vegetation is commonly a narrow linear feature with low vegetative density, and often obscured by overhanging vegetation. Other vegetation types were rarely classified as spit or berm vegetation, leading to a high user's accuracy rate.

Mixed algae had relatively low Producer's and User's Accuracy rates. Confusion between mixed algae and other vegetation types was expected, given that mixed algae is a combination of multiple vegetation types. Mis-classification could have been due to differences in the relative contribution of vegetation types to the overall spectral signature or to temporal changes in species composition.

Green algae had a low Producer's Accuracy rate. We attribute this to the relatively ephemeral character of green algae in comparison to the other vegetation types.

The assumption of the accuracy assessment is that the error matrix accurately represents the classification effort as a whole. Congalton (1991) reviews a number of factors that impact the analysis, including the classification scheme and sampling design. The classes of any classification scheme should be mutually exclusive and totally exhaustive. If the classes of a system are mutually exclusive, a site will fall into one and only one class; if a system is exhaustive, all sites can be assigned to an existing category. In our system, the present eight classes do not exhaust the possible vegetation community compositions in the nearshore environment. For example, field staff have reported sites where green algae and eelgrass are intermixed at the 13.123 feet (four meters) minimum mapping threshold. The combination of green algae and eelgrass is not classed appropriately as 'mixed algae'. These sites were classified as eelgrass, because eelgrass is a more persistent vegetation and a more functionally recognized constituent

Welch (1981) has suggested that an image's spatial resolution should be less than half the size of the target feature measured in its smallest dimension. Therefore, the minimum mapping unit for the vegetation inventory should not be equal to spatial resolution of the sensor. Assuming that the sensor's pixels will align precisely with the ground feature is unrealistic. However, altering either of these variables has strong implications for the program. For example, increasing the minimum mapping unit to a value twice the sensor's spatial resolution would result in a higher degree of generalization and many narrowly-banded vegetation features that are biologically important in the nearshore would not be considered because they fall below the MMU. Selecting a finer sensor spatial resolution would result in much larger data sets, increased processing time, and increased data management costs

Generalization & Conversion _(to Table of Contents)_

Based on the assessment/review work of the marine scientists, modifications were made to the classified file. After final adjustments, the classified raster was converted to vector format for subsequent use and analysis in DNR's GIS. Vector data formats are a DNR standard for analysis and cartographic production. In addition, the generalized coverage provides users of systems with limited raster capabilities with a vector data set of a manageable size for many computer configurations.

As part of the data conversion, generalization was required to reduce the number of features and arcs in the coverage to a manageable number. The objective was to simplify the coverage while maintaining the salient characteristics of vegetation features at an appropriate scale. The following evaluation criteria were used to select the best data conversion methods:

Significant reduction of the number of features and arcs in the polygon coverage

Less than 10 percent variation in total acreage per vegetation class between the ungeneralized raster data and the final vector coverage.

Similar visual appearance of ungeneralized and generalized features, when viewed at 1:12,000 scale.

Minimization of required feature-by-feature editing, to achieve consistent results throughout the study area and to increase time efficiency.

After initial testing of generalization and conversion in small areas, the following steps were applied:

Mosaic blocks were joined into a single grid file for the study area, and then separated by vegetation type for generalization.

An ARC/INFO GRID (ESRI, Redlands, California) focal filter function was used to smooth feature boundaries. Smoothed grids for each vegetation type were then recombined according to a hierarchy, so that in cases where a pixel was assigned multiple vegetation values, the higher priority vegetation type was retained. The assignment hierarchy was based on the relative significance of vegetation types in management and environmental decision making: eelgrass (highest), kelp, salt marsh, red algae, spit or berm, mixed algae, brown algae, green algae (lowest). The recombined grid was then converted into a polygon coverage.

Features with an area fewer than four pixels (approximately 680 square feet) were eliminated. The elimination decreased the total number of features by 58%, while changing the total acreage by less than 5 percent. In determining the size of features to eliminate, the effect of elimination on visual appearance turned out to be more important than the effect on total vegetation acreage because the size distribution of vegetation features was weighted towards the small class sizes. As a result, the visual appearance of the coverage could change markedly without a corresponding change in acreage. The narrow, linear vegetation features were most affected by area elimination thresholds. They were evaluated at 1:12,000 scale to decide which elimination threshold best maintained feature representation.

While the generalization did not significantly affect the areal extent of vegetation, it changed the frequency distribution of size classes. Fifty-eight percent of the total number of vegetation features were eliminated. This effect of generalization should be considered when using the vector data set.

SHORELINE CHARACTERISTICS INVENTORY *(to Table of Contents)*

Classification System

A Marine and Estuarine Habitat Classification System for Washington State (Dethier, 1990) is a hierarchical system that is based on the widely used U.W. Fish and Wildlife Service's *National Wetlands Inventory (NWI) Classification* (Cowardin *et al.*, 1979). Major adaptations in the Washington State system include an additional level describing Energy (waves and currents), description of substrate in all habitats, and description of aquatic vegetation as diagnostic and common species. The classification system summary is listed in Table 6.

Since Dethier's classification system does not have an integrated mapping methodology, methods were developed by the Nearshore Habitat Program (Berry and Ritter, 1997). The shoreline characteristics inventory delineated the following levels: System, Subsystem, Class, Subclass, Energy, Water Regime. Classification was implemented according to Bailey *et al.* (1993). Water Chemistry was not photo-interpreted due to a lack of visual cues that reliably indicate salinity regime. Diagnostic and common aquatic vegetation species were not included because they are provided in a separate vegetation inventory.

There are inconsistencies in how the Class and Subclass categories are defined in Dethier's classification system and how they are used in common implementations. The shoreline characteristics inventory system describes substrate at the Class and Subclass levels (e.g., Unconsolidated, Sand). However, habitat descriptions in Dethier's classification use Subclass rather than Class level categories (e.g., Sand). One exception is the Artificial Class, where no Subclasses are used. Most implementations and reviews also use Subclass for every category except Artificial, including the state's Compensation Schedule for Marine and Estuarine Waters (WAC 173-183-400), Puget Sound Estuary Program (Simenstad *et al.*, 1991), and in trans-boundary implementations (Harper and Morris, 1994; Frith *et al.*, 1993). The shoreline characteristics inventory adopted this approach, but changed the name of the attribute to Substrate to avoid mixing the Class and Subclass values. The Substrate category includes descriptions at the Subclass level of detail for consolidated and unconsolidated substrates and at the Class level of detail for Artificial substrates. Code tables are provided to translate to Class and Subclass categories.

Substrate composition at extreme high water was classified to capture ecological differences at the land-water interface. Substrate type at this tidal level was divided into three categories: bedrock, artificial, and unconsolidated.

Table 6. Overview of *A Marine and Estuarine Classification System for Washington State*.

System	Subsystem	Class	Subclass	Energy	Water Regime
Marine	Intertidal	Consolidated	Bedrock Boulder Hardpan	Exposed Partially Exposed Semi-Protected Protected	Eulittoral Backshore
		Unconsolidated	Cobble Mixed Coarse Gravel Sand Mixed Fine Mud Organic		
		Reef			
		Artificial			
	Subtidal	Consolidated	Bedrock Boulder Hardpan	High Moderate Low	Shallow Deep

		Unconsolidated	Cobble Mixed Coarse Gravel Sand Mixed Fine Mud Organic		
		Reef			
		Artificial			
Estuarine	Intertidal	Consolidated	Bedrock Boulder Hardpan	Open Partly Enclosed Lagoon Channel/Slough	Eulittoral Backshore
		Unconsolidated	Cobble Mixed Coarse Gravel Sand Mixed Fine Mud Organic		
		Reef			
		Artificial			
	Subtidal	Consolidated	Bedrock Boulder Hardpan		Shallow Deep
		Unconsolidated	Cobble Mixed Coarse Gravel Sand Mixed Fine Mud Organic		
		Reef			

		Artificial			

Delineation Methods *(to Table of Contents)*

Intertidal shoreline characteristics were delineated on mylar overlaid on stable base, screened prints on photographic paper of DNR's 1:12,000 scale orthophoto maps. The mylar overlays had reference information plotted on them, including geographic control marks, the NWI Extreme Low Water line and the DNR water level line. A Bausch and Lomb Zoom Transfer Scope was used to superimpose annotated aerial photographs, maps, and National Oceanic and Atmospheric Administration (NOAA) nautical charts onto the mylar. Lines and polygons were traced directly onto the mylar overlay and coded using an ultra fine point colored permanent marker.

Data sources used to delineate shoreline characteristics include:

- Color infrared aerial photography collected by DNR Nearshore Habitat Program in 1992 (1:13,000 scale), 1996 (1:11,000 scale).
- Black and white aerial photography collected by DNR Photo and Map Sales in 1995 (1:12,000 scale).
- Field notes annotated on aerial photography and multispectral imagery collected throughout the study area from 1992 through 1997. Many sites also include 35 mm slides.
- NOAA NOS (National Ocean Service) nautical charts 18427, 18430, 18424, and 18400.
- U.S. Geological Survey 7.5 Minute Series (Topographic) maps.
- The Washington Coastal Zone Atlas (Department of Ecology, 1978).
- Intertidal transect information measuring percent cover of surface substrates and organisms collected by DNR Nearshore Habitat Program during 1995.
- U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI) wetlands classification of the Puget Sound in paper and digital format.

The minimum mapping unit was determined to be approximately 20,000 square feet (1,800 square meters) on the ground, approximately 0.5 acre. The threshold was set by experimenting with the size of features that could be reliably delineated and digitized at base map scale using current methods. Features smaller than the minimum mapping unit were delineated in areas where the intertidal zone was created by estimating planimetric intertidal width and buffering anthropogenic features such as dikes and jetties.

The geographic boundaries of the Estuarine System and Marine System were adopted from The Habitat Classification System for Washington State (Dethier, 1990). The Intertidal Subsystem was delineated to show Substrate, Energy, and Water Regime (Table 6). The following features were delineated:

- Extreme Low Water Line (ELW) - The ELW line divides the Intertidal and Subtidal areas at the Subsystem level, and is the seaward extent of classification in the pilot study. NOAA estimates ELW in the study area to range from -4.0 to -4.5 feet. The location of ELW was estimated by superimposing low-tide aerial photographs of known tidal height onto the orthophotos. This line was then extrapolated seaward based on comparison to superimposed bathymetric lines from USGS topographic maps or NOAA charts. Our estimate was compared to the National Wetlands Inventory ELW line, and in portions where the two estimates did not differ significantly, NWI's ELW line was used.

- Extreme High Water Line (EHW) - The EHW line defines the upland extent of classification. The location of EHW was estimated using visual cues such as vegetation changes, cliffs, bluffs, and seawalls. The digital line was created by altering the plotted DNR Water Level Line as necessary based on comparison to aerial photographs and topographic maps. On wide beaches, EHW is significantly farther inland than the DNR Water Level Line. On narrow beaches, at the spatial resolution of this mapping project, EHW is in the same location as the DNR Water Level Line. Dynamic segmentation procedures were applied to the EHW line to designate substrate type at the land-water interface.

- Substrate Polygons - Areas of homogenous substrate types, as defined by the Substrate categories (Table 6 and Dethier 1990). Since the inventory was limited to the Intertidal zone, the seaward and landward boundaries of substrate polygons were the ELW and EHW lines. In delineating Substrate, field data describing substrate size were transferred onto mylar. In areas between field data, pattern, color, texture and morphological cues were used to delineate boundaries between categories.

- Energy Polygons - Areas of homogenous energy, classified by comparison to Dethier (1990). The Energy level classes are broad enough to be applied to a whole section of shoreline (Bailey *et al.*, 1993). A single Energy value was assigned to the upper and lower intertidal portions of a segment of shoreline with the exception of Backshore areas in Open Energy regimes, which were assigned Partly Enclosed Energy value.

- Water Regime Polygons - The classification defines regularly inundated areas between ELW and mean high water of spring tides (MHWS) as Eulittoral, and rarely inundated areas between MHWS and EHW as Backshore (Dethier, 1990). Backshore areas along the shoreline rarely met the minimum mapping unit threshold. As a result, few Backshore polygons were delineated

In practice, the EHW and ELW lines were delineated first. Then, within the Eulittoral zone defined by these lines, separate polygons were delineated and coded whenever any of the attribute values changed. Since substrate values changed most frequently, substrate polygons were delineated. Then, Energy and Water Regime values were delineated by outlining and labeling one or more substrate polygons and adding polygons as required.

Each orthophoto was annotated with complete polygons. When polygons spanned onto adjacent orthophotos, complete polygons were drawn on each orthophoto so that the boundary lines overlapped. Overlapping lines were later dissolved during GIS processing.

Digital Data Structure *(to Table of Contents)*

A single polygon theme of integrated terrain units was created (Dangermond *et al.*, 1982). The integrated theme simplified production since the boundaries of different levels were often coincident, and obviated potential spatial inconsistencies between layers of information. Attributes for each Shoreline Characterization parameter were associated with each polygon. A series of 3-letter codes was used to code polygon attributes (Table 7). Upland areas were coded 'upl' to denote upland for all attributes.

Each arc was coded to describe the type of boundary it delineated (Table 8). Because a single arc was often associated with changes in the values of multiple parameters, we prioritized the boundary value to be selected based on data display and analysis goals. Elevation lines defining the upper and lower limit of the Intertidal Subsystem were prioritized highest, followed by System boundaries, Backshore boundaries, Energy boundaries, and Substrate boundaries.

Dynamic segmentation was used to define substrate changes along the Extreme High Water Line (EHW). The three substrate type categories are 'bed' for bedrock sections of the line, 'art' for artificial substrates, and 'unc' for unconsolidated substrate. Changes in substrate were coded at event breaks.

Digitizing and Review *(to Table of Contents)*

Line data were manually digitized from each 1:12,000 map manuscript into a tile registered to DNR's 5000-foot grid GIS registration tics. After tiles were digitized and checked, coverage tolerances were set as follows:

Tolerance	Units (feet)
Fuzzy	1
Dangle	0
Edit	40
Node Snap	40
Weed	10
Grain	10
Snap	10

Table 7. Polygon Attribute Codes of Shoreline Characteristics Inventory

Attribute	**Code**	**Description**
System	mar	Marine
	est	Estuarine
Subsystem	int	Intertidal
	sub	Subtidal
Substrate	bed	Bedrock
	bou	Boulder
	har	Hardpan
	cob	Cobble
	mco	Mixed Coarse
	gra	Gravel
	san	Sand
	mfi	Mixed Fine
	mud	Mud
	org	Organic
	art	Artificial
	upl	Upland
Energy (estuarine)	opn	Open
	pen	Partly Enclosed
	lag	Lagoon
(marine)		

	csl	Channel/Slough
	exp	Exposed
	pex	Partially Exposed
	spr	Semi-Protected
	pro	Protected
Water Regime	bks	Backshore
	eul	Eulittoral
	upl	Upland

Table 8. Line Attribute Codes of Shoreline Characteristics Inventory

Significant Boundary Code (Sigbnd_cd)	Description
11	Boundary between upland and Marine/Estuarine areas. Approximate Extreme High Water Spring (EHWS).
12	The boundary between Subtidal and Intertidal areas. Approximate Extreme Low Water (ELW).
13	Boundary between Marine and Estuarine Systems.
14	Boundary between Backshore areas and Eulittoral areas. Approximate mean higher high water.
15	Boundary between areas with different Energy values.
16	Boundary between areas with different Substrate values.

99	Boundary at the edge of the study area or at the edge of digitized sections.

Individual, topologically correct coverages were created for each of the 33 orthophotos. Attribute values for polygon and line features were then added. Next, check plots of the tiles were reviewed for attribute and line work accuracy. Coverage edge matching was performed and corrections were made where necessary. Coverage tiles were joined into a single geo-data set for the entire study area and then checked for proper arc and polygon topology. Next, tile boundaries were eliminated to create a seamless data set.

Once the polygon and line features were established, the Extreme High Water Line (EHW) was converted to a route feature. Shoreline substrates, (bedrock, artificial, and unconsolidated), were identified using digitized break points. Once the routes were defined, continuous linear events were developed using the digitized points as event breaks. The search radius for event matching was 10 feet. The events were interactively assigned substrate types based on each 1:20,000 map manuscript. A final set of check plots were generated and reviewed for line work and attribute coding accuracy.

DATA USAGE CONSIDERATIONS *(to Table of Contents)*

Introduction *(to Table of Contents)*

The Nearshore Habitat Program goal is to provide information that is sufficiently detailed and accurate for decision making and that is available Puget Sound-wide. This purpose impacts the intended uses of these data. Data were created for general planning purposes, and should not be used for site-specific analysis or to replace site-specific surveys. We will use the data set for assessing resources for scientific and management purposes across areas of Puget Sound.

To meet multiple user needs, vegetation types and shoreline characteristics data are available digitally and in paper format. A map series showing the vegetation and habitat data at 1:24,000 scale has been designed for use by nearshore habitat and aquatic resource managers. Digital data, metadata, and methods documentation are available on CD-ROM through the Nearshore Habitat Program.

Ultimately, it is the user who must assess the appropriateness of a data set for a particular use. Usage is constrained by how the data were defined, collected, processed, and the accuracy of the resulting data set. Key usage considerations for the vegetation and shoreline characteristics data are discussed below

Vegetation Type Usage Considerations _(to Table of Contents)_

The methods employed for inventorying vegetation determine the limitations of the final classification. The following factors impact usability of results:

- The inventory reflects vegetative conditions at a single period in time (July 14, 15, or 30, 1996). The data do not provide information on peak conditions, seasonal variation or interannual variation.
- Vegetation type classification was based on the dominant vegetation type present. Other types of vegetation may be present in abundances of less than 30%.
- Due to water conditions, subtidal vegetation that does not form a canopy may not be distinguished. Therefore, conclusions regarding the presence or absence of subtidal vegetation should not be drawn based on this data set.
- Vegetation patches smaller than one pixel in size are not likely to be detected. At a spatial resolution of approximately 169 square feet (16 square meters), many small patches of nearshore vegetation are below the horizontally measured threshold. Examples of features that are regularly smaller than the minimum threshold include spit and berm vegetation and intertidal vegetation along narrow shorelines. Furthermore, the detection of vegetation patches the same size or slightly larger than one pixel will be affected by how the sensor's pixel grid overlays the vegetation feature. If a feature is divided between multiple pixels, each individual pixel may not contain sufficient vegetative cover to be classified as having vegetation. Therefore, analysis of the raster data set should consider that vegetated sites less than 2 pixels in size may not be represented in the data set. Analysis of the vector data should be based on a larger minimum mapping unit (see Shoreline Characteristics Usage Considerations section below).
- Low density vegetative cover is more likely to escape detection. However, this threshold was not formally evaluated.
- The data set has known accuracy limitations. We estimated overall accuracy, and producer's and user's accuracy for each vegetation class (see Vegetation Inventory, Classification Accuracy Assessment section). These statistics should be considered when using the vegetation data. Additionally, the influence of the sampling method design on subsequent uses of the data must be considered. Accuracy assessment sites were not selected randomly; site accessibility was a major consideration in selection, and sites were stratified by vegetation type to assure that examples from each type were included. The vegetation type for subtidal accuracy assessment sites were not verified by diving surveys. These methodological considerations limit how closely the accuracy assessment results represent the population surveyed. Finally, the accuracy assessment relates only to the raster data set, not the generalized vector data set.

- The vegetation data set was rectified using GPS data collected in-flight (differential corrections were applied in post-processing), and control gained from Washington State Department of Natural Resources' digital orthographic photography. Most areas were mapped to within approximately 40 feet (12 meters) relative to the control points. Positional accuracy is poorest in areas surrounded by water where there are few available ground control points. Positional agreement between the vegetation data set and data sets developed from other sources may vary. The gray scale CASI image from the original data set is available. When using the gray scale imagery as a backdrop for the vegetation data set, positional agreement is complete.

- Life cycle characteristics of different vegetation types affect detection levels. For ephemeral vegetation, such as green algae, the time of data collection will have a major impact on the classified abundance and distribution. Subtidal species are likely to be under-represented. Features that are characteristically covered or obscured by overhang, such as salt marsh or algae on steep rocky shores, are likely to be under-represented.

- Because the gradient between these wetland types is often gradual. Some errors exist in the classification of salt marshes and fresh water marshes. Some salt marshes were excluded from the classification and some fresh water marshes were included in the classification as salt marsh.

Raster and generalized vector versions of the vegetation data are available. The raster imagery contains the original classification results and was not generalized. Accuracy assessment was completed on the raster data set. DNR will use the raster data set for detailed data analysis and areal estimates.

The vector format was created for use on systems with limited raster capabilities. To decrease file size, features smaller than 4 pixels in area were deleted, making the minimum mapping unit for the vector vegetation data approximately 850 square feet. The accuracy assessment results do not apply to the generalized vector data set. Large scale or detailed usage of the vector data is not recommended, and acreage calculation based on the vector data set are not recommended. DNR will use the vector data set for general-purpose information display and cartographic production.

Shoreline Characteristics Usage Considerations *(to Table of Contents)*

The shoreline characteristics data can be analyzed using line attributes and multiple polygon attributes. Some habitat assessment policies and protocols that employ this classification and can be applied directly in analysis include EPA Puget Sound Estuary Program's Estuarine Habitat Assessment Protocol, WAC 220-110, and WAC 173-183.

The methods employed for inventorying shoreline characteristics determine the detection limitations of the final classification. The following factors should be considered when using the data set:

- Intertidal elevation boundaries were estimated visually, not surveyed. Uncertainty associated with this method should be taken into account when applying the data set.
- Given a minimum mapping unit of approximately 0.2 hectares (0.5 acres), many intertidal zones fall below the minimum threshold. Analysis of these data should take into consideration that many narrow, linear habitats related to tidal elevation were below the mapping resolution. Examples include, bands of substrate found at characteristic tidal elevations, and Backshore areas.
- Energy classification was applied broadly to correspond with the degree of detail provided by the Energy classes (Bailey *et al*., 1993). Classification was applied to sections of shoreline rather than individual polygons, with the exception of Backshore areas, which were never assigned a value of Open. Given these methods, the minimum mapping unit for Energy values was significantly larger than for other attributes, with the exception of Backshore areas behind Open Intertidal areas, these were automatically classified as Partly Enclosed. As a result, Energy values should be assessed over larger areas than other classification categories.
- A gray scale CASI image is available as a backdrop for the shoreline characteristics data set. Since the shoreline characteristics data set was delineated on orthophoto base maps, positional agreement with the image varies. The CASI image was rectified using GPS data collected in-flight (differential corrections were applied in post-processing), and control gained from orthophoto base maps. Most areas were mapped to within 40 feet (12 m) relative to the control points. Positional accuracy is poorest in areas surrounded by water where there are few available ground control points. Digital orthophotography, available through DNR, has the best positional agreement with the shoreline characteristics coverage.

IN CLOSING *(to Table of Contents)*

The Nearshore Habitat Program balances the need to provide information for decision making that is sufficiently detailed and accurate, against the reality of covering a large study area with limited resources. The technical and environmental complexity of our task makes coordination among the marine science, remote sensing, and GIS staff critical.

We see strengths and weaknesses in the methods outlined here. Multispectral classification of vegetation is a powerful tool for delineating vegetation bed area and patch complexity. However, our multispectral data do not commonly capture the subtidal extent of vegetation in this region, so changes in the overall acreage of vegetation beds cannot be tracked. The Shoreline Characteristics inventory provides estimates of the areal extent of intertidal habitat types using a classification system shared by multiple agencies for diverse management purposes. Weaknesses include inconsistencies in the classification system and inefficiencies in the data creation process.

The methods outlined here describe only one of three systems that we are using now to inventory and monitor nearshore habitat health. Multiple systems were adopted to respond to the differing temporal and spatial resolution of our many monitoring questions. The ShoreZone System has been adopted to provide a low resolution, state-wide characterization of nearshore biological and physical resources. High resolution methods for monitoring reference sites are now being developed. We will continue to refine our methods in order to further improve our information quality and usefulness.

NOTICE *(to Table of Contents)*

The information presented in this paper does not necessarily reflect the views of the Washington State Department of Natural Resources, and no official endorsements should be inferred. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ACKNOWLEDGMENTS *(to Table of Contents)*

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REFERENCES *(to Table of Contents)*

Aitken, J., G. Borstad, and L. Deysher, February 1995. Nearshore Project: Multispectral Data Collection and Image Processing Consultation. Unpublished report prepared by Borstad

Associates Ltd. for Washington State Department of Natural Resources, Aquatic Resources Division, Olympia, WA.

Aitken, J., Wes MacLeod, and G. Borstad, June 1995. Nearshore Habitat Inventory Project Task 1: Final Project Plan. Unpublished report prepared by Borstad Associates Ltd. for Washington State Department of Natural Resources, Aquatic Resources Division, Olympia, WA.

Bailey, A., K. Ward, and T. Manning, 1993. A Field Guide for Characterizing Habitats using A Marine and Estuarine Habitat Classification System for Washington State. Washington Department of Natural Resources, Division of Aquatic Lands.

Bailey, A, H. Berry, B. Bookheim, and D. Stevens, 1998. Probability-Based Estimation of Nearshore Habitat Characteristics. In Proceedings of Puget Sound Research '98 Conference. Puget Sound Water Quality Authority, Olympia, WA.

Berry, H., and R. Ritter, 1997. Puget Sound Intertidal Habitat Inventory 1996: Vegetation and Shoreline Characteristics Classification Methods. Washington State Department of Natural Resources, Aquatic Resources Division, Nearshore Habitat Program.

Borstad, G., 1996. The Nearshore Habitat Inventory Project Task 7: Project Summary Memorandum. Unpublished report prepared by Borstad Associates Ltd. for Washington State Department of Natural Resources, Aquatic Resources Division, Olympia, WA.

Borstad, G., 1997. The Nearshore Habitat Inventory Project Task 7: Data Quality Assessment Report and Task 8: Project Summary Report. Unpublished report prepared by Borstad Associates Ltd. for Washington State Department of Natural Resources, Aquatic Resources Division, Olympia, WA.

Bortleson, G.C., M.J. Chrzastowski, and A.K. Helgerson, 1980. Historical Changes of Shoreline and Wetland at Eleven Major Deltas in the Puget Sound Region, Washington. Atlas HA-617. US Geological Survey.

British Columbia/Washington Marine Science Panel. 1994. The Shared Marine Waters of British Columbia and Washington: a Scientific Assessment of Current Status and Future Trends in Resource Abundance and Environmental Quality in the Straits of Juan de Fuca, Strait of Georgia, and Puget Sound. Province of British Columbia, Canada. 119 pp.

Congalton, R., 1991. A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data. *Remote Sensing of Environment*, 37:35-46.

Cowardin, L., V. Carter, F. Golet, and E. LaRoe, 1979. *Classification of Wetlands and Deepwater Habitats of the United States*. U.S. Fish and Wildlife Service. FWS/OBS-79/31.

Dangermond, J., B. Derrenbacher, and E. Harnden, 1982. Description of Techniques for Automation of Regional Natural Resource Inventories. Environmental Systems Research Institute, Inc.

Dayton, P.K. 1985. Ecology of kelp communities. Johnston, R. F. (Ed.). Annual review of Ecology and Systematics, Vol. 16. Ix+504 p. Annual Reviews Inc.: Palo Alto, Calif., USA. Illus. p. 215-246.

Department of Ecology, 1980. Washington Coastal Zone Atlas. Olympia, WA.

Dethier, M., 1990. *A Marine and Estuarine Habitat Classification System for Washington State*. Washington Natural Heritage Program, Washington State Department of Natural Resources, Olympia, WA. 56 pp.

Duggins, D.O., 1988. The effects of kelp forests on nearshore environments: biomass, detritus, and altered flow, The Community Ecology of Sea Otters, ed. G.R. Van Blaricom and J.A. Estes (Berlin: Springer-Verlag, 1988): 192-201.

Foster M.S. & D.R. Schiel, 1985. The Ecology of Giant Kelp Forests in California: A Community Profile. U.S. Fish and Wildlife Service Biol. Report 85(7.2), 152 pp.

Frith, H., G. Searing, P. Wainwright, J. Harper, and B. Emmett, 1993. Review of Habitat Classification Systems and an Assessment of Their Suitability to Coastal B.C. Report EA574, LGL Limited, Sidney, BC.

Harper, J.R., M.C. Morris, and P.D. Reimer. 1994. Shoreline Habitat Mapping, San Juan Island, Washington. Report to the Washington State Department of Fish and Wildlife. 9 pp + appendices.

Lillesand, T. and R. Kiefer, 1994. *Remote Sensing and Image Interpretation*. John Wiley & Sons, Inc., New York.

Mac Dougall, E., 1976. *Computer Programming for Spatial Problems.* Edward Arnold, London.

Monitoring Management Committee, 1988. Puget Sound Ambient Monitoring Program. Final Report.

Phillips, R.C. 1984. The Ecology of Eelgrass Meadows in the Pacific Northwest: A Community Profile. U.S. Fish and Wildlife Service FWS/OBS-84/24. 85 pp.

Puget Sound Water Quality Authority, 1992. Puget Sound Environmental Atlas 1992 Update.

Puget Sound Water Quality Authority, 1986. State of the Sound 1986 Report. Puget Sound Water Quality Authority, Seattle, WA.

Scagel, R.F., P.W. Garbielson, D.J. Garbary, L. Golden, M. W. Hawkes, D. C. Lindstrom, J. C. Oliveira and T. B. Widdowson, 1989. A Synopsis of the Benthic Marine Algae of British Columbia, Southeast Alaska, Washington and Oregon. Phycological Contribution Number 3. Department of Botany, University of British Columbia, Vancouver, British Columbia, Canada.

Seliskar, D.M. and J.L. Gallagher. 1983. The Ecology of Tidal Marshes of the Pacific Northwest Coast: A Community Profile. U.S. Fish and Wildlife Service, Division of Biological Services, Washington, D.C. FWS/OBS-82-32. 65 pp.

Simenstad, C.A., C.D. Tanner, R.M. Thom, and L.L. Conquest, 1991. Estuarine Habitat Assessment Protocol. US Environmental Protection Agency, Puget Sound Estuary Program. EPA 910/9-91-037. 201 pp.

Swain, P. and S. Davis, 1978. *Remote Sensing: the Quantitative Approach.* McGraw-Hill Book Company, New York.

Thom, R.M. and L.A. Hallum. 1991. Historical changes in the distribution of tidal marshes, eelgrass meadows, and kelp forests in Puget Sound. Pp. 302-313 In Proceedings of Puget Sound Research '91 Conference. Puget Sound Water Quality Authority, Olympia, WA.

Washington Administrative Code. Title 220-110, Department of Fisheries Hydraulic Code Rules.

Washington Administrative Code. Title 173-183, Preassessment Screening and Oil Spill Compensation Schedule Regulations.

Washington Administrative Code. Title 365-190, Community Development: Minimum Guidelines to Classify Agriculture, Forest, Mineral Lands, and Critical Areas.

Washington State Department of Natural Resources, 1991. Policy-0300: Managing and Protecting Wetlands.

Welch, R., 1981. Sensor and Image Resolution Requirements for Urban Studies. Presentation at the annual meeting of the Southeastern Division of the Association of American Geographers, Atlanta, GA.

Wheeler, W.N., 1990. Kelp forests of British Columbia: A unique resource. Ministry of Agriculture and Fisheries, Aquaculture and Commercial Fisheries Branch, Province of British Columbia. 91 pp.

Wyllie-Echeverria, S., A.M. Olson and M.J. Hershman (eds.), 1994. Seagrass Science and Policy in the Pacific Northwest: Proceedings of a Seminar Series. (SMA 94-1). EPA 910.